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Fluxes of nitrous oxide in tilled and no-tilled boreal arable soils

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ABSTRACT

Agricultural management practices can have a significant effect on the emissions of nitrous oxide (N_2O) from soils. The aim of this 2-year study was to investigate the effects of no-till (NT) and reduced tillage (RT) practices on annual fluxes of N_2O from different soil types typical for the boreal region of northern Europe. We measured the fluxes of N_2O in conventional tillage (CT) and NT at four sites of which two also had RT treatment. No-till and RT practices had been implemented 8–10 years before our study was initiated. Chamber measurements were carried out fortnightly in 2008–2010 on clayey (sites 1–3) and coarse (site 4) soils. Annual cumulative emissions of N_2O varied from 2.4 to 8.3 in CT, 2.5–6.5 in RT and 4.9–10.2 kg N_2O-N ha^{-1} in NT. High peaks in measured N_2O fluxes occurred during and after thawing of the soil in April and after fertilization and high rain events. No-till or RT did not have any significant effects on soil C or N stocks or potential denitrification of the 0–20 cm soil layer. Dry bulk density and water-filled pore space (WFPS) were generally higher under NT compared to CT, most probably being the main reasons for the increased N_2O emissions in the NT systems. Soil temperature varied less in NT by being higher during the colder periods of the year and slightly cooler during hot summer days. In conclusion, our results indicate that NT induces a risk of increased N_2O emissions in clayey soils in small grain spring cereal agroecosystems in Northern European boreal climate.

1. Introduction

Agricultural lands are a major contributor to global anthropogenic emissions of greenhouse gases and accounted for about 60% anthropogenic N_2O emissions in 2005 thus enhancing global climatic change (Smith et al., 2007). Most of this increase in N_2O emissions is due to enhanced microbial N_2O production that is associated with human perturbations to the nitrogen cycle. Most of the N_2O produced during microbial processes in soils is released to the atmosphere as so called direct emissions from fields but part is also from indirect emissions, e.g. N_2O produced from leached or volatilized nitrogen (Nevison, 2000). The main microbial processes contributing to N_2O emissions are anaerobic denitrification which is reduction of nitrate to N_2O and N_2 and aerobic nitrification that produces N_2O as a side product when O_2 is limited in the soil (Doran, 1980; Groffman, 1984; Six et al., 2002; Smith et al., 2003). The need to find ways of reducing greenhouse gas emissions from arable soils is evident. No-till (NT) management is considered a practice that helps preserve water and carbon in the surface layer of the soil (Lal, 1997), as well as saving fuel and labor compared to conventional tillage (CT). In comparison to CT soils, NT soils often have a more dense structure (Schjønning and Rasmussen, 2000; Tebrügge and Düring, 1999) and higher moisture content (Gregorich et al., 2008; Sharratt, 1996), hence favoring the activity of anaerobic denitrifying bacteria.

Since N_2O is as a greenhouse gas approximately 300 times more potent than CO_2, it has been estimated that its increase in NT could offset 75–310% of the advantage gained from carbon sequestration under NT (Li et al., 2005). Field measurements have shown both decreased and increased emissions of N_2O under NT (Aulakh et al., 1984; Ball et al., 1999; Chatskikh and Olesen, 2007; Kaharabata et al., 2003; MacKenzie et al., 1998; Ussiri et al., 2009), demonstrating great variability depending on different soil and climatic conditions. Mathematical models have also tried to capture the effect of different management practices on N_2O emissions with varying results (Li et al., 1996; Mummey et al., 1998). The different duration of the experiments may partly explain the contradicting observations; Six et al. (2004) reported results of a meta-analysis indicating increased N_2O emissions during the first years after converting to NT, with emissions reducing back to normal levels or less in humid climate after 20 years of NT. Rochette (2008), on the other hand, argued that N_2O fluxes only increase from poorly aerated soils under NT, especially in cool humid climates. Grandy et al. (2006) found that N_2O fluxes did not increase under NT in a 10-year study

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and only offset 56–61% of the carbon sequestered on loamy soils in south-western Michigan.

Reduced tillage (RT, shallow stubble cultivation) is a treatment between CT and NT treatments disturbing the soil to a shallower depth than CT. Effects of RT on N_2O emissions vary between different studies of which some report no change (Abdalla et al., 2010; Elmi et al., 2003) and some increased emissions (Beheydt et al., 2008) or decreased emissions under RT compared to CT (Chatskikh et al., 2008).

At a global scale, the adoption of NT management has increased more than 230% during the last 10 years, reaching 111 million ha in 2009 (Derpsch et al., 2010). In Europe, the adoption of NT has been clearly slower than, for instance, in North and South America (Soane et al., 2012). In Finland, the area of agricultural land converted to NT has, however, increased rapidly and is estimated to have reached over 150,000 ha in only a little over 10 years after it was introduced to farmers (Tike, 2011), and being relatively one of the highest in Europe at present. About 13% of the annually sown area is now under NT and 25% under RT. The reduced cost of fossil fuel and labor compared to CT has promoted adoption of NT (e.g. Derpsch et al., 2010). No-till has been reported to be advantageous with respect to erosion control in boreal areas (Børresen and Uhlén, 1991; Puustinen et al., 2007) and to reduce nitrogen leaching from arable fields (Syswerda et al., 2012). As one of the measures to decrease erosion and nutrient transport from land to watercourses, Finnish Agri-Environmental Programme and the accompanying Support Scheme encourage increasing the crop or crop residue covered area outside the growing season when erosion and particulate phosphorus leaching peak (Puustinen et al., 2007).

It was estimated that if all the European agricultural soils that could be converted to NT adopted this management practice, N_2O emissions would increase to 20.5 Tg of carbon equivalents emitted per year (Smith et al., 2001). However, data on the effects of different management practices on emissions of N_2O in boreal climate is scarce. The aim of this 2-year study was to estimate the magnitude of N_2O fluxes in CT, NT and RT treatment on soil types typical for the boreal region of northern Europe. Measurements of several environmental and soil parameters were taken to elucidate the underlying factors controlling N_2O emissions under the different management practices.

2. Materials and methods

2.1. Study sites and soil parameters

This study took place on four pairs of CT and NT fields in southwestern Finland from June 2008 to June 2010. Two fields (sites 1 and 2) were located in Jokioinen (60°49′N and 23°30′E). One field (site 3) was located in Vihti (60°21′N and 24°22′E) and one field pair (site 4) in Säkylä (60°58′N and 22°31′E). Sites 1–3 were field experiments (randomized complete-block design with four replicates) and the fields of site 4 belong to neighboring farmers (four replicated measurements sites/field, plot size 100-250 m^2). Soils at sites 1–3 were classified as Vertic Cambisol and at site 4 as Eutric Regosol (FAO, 2006). Soil properties and other site parameters are shown in Table 1. All sites had CT and NT treatments. In addition, sites 1 and 2 had plots with RT treatment.

No-till practice, in which the crop was sown without prior soil tillage, had been used at the study sites for 8–10 years before our study begun. In autumn (September/October), the soil was mouldboard ploughed to a depth of 20–25 cm on CT plots and soil was stubble cultivated with tined cultivator to 10–15 cm on RT plots. In spring, CT and RT plots were first leveled by a harrow and then rotary or S-tine harrowed to 4–5 cm depth to prepare the seedbed. Spring barley (*Hordeum vulgare*) was cultivated at sites 1, 2 and 4. Spring oilseed rape (*Brassica rapa* subsp. *oleifera*) was cultivated at site 3 during the 2008 growing season and spring wheat (*Triticum aestivum*) during the growing season of 2009. All treatments were sown and fertilized in May. Conventional tillage and RT were sown with combined drill (shoe coulters) which placed seed (to 4–5 cm depth) and fertilizer (7–8 cm) at the same time in separate rows. The seed and fertilizer row spacing was 12.5 and 25 cm, respectively, and had rolling wheels behind the drill (sites 3 and 4). No-till was directly sown to 3–5 cm depth with combined drill having triple disc coulters (site 4, row space 15 cm, front single disc coulter is tilling and rear double disc coulter is sowing with roller wheels behind the sowing coulters), double disc coulters (sites 1 and 2, row space 14.5 cm, packing wheels behind the drill) or single disc coulters (site 3, row space 12.5 cm, rolling wheels behind the drill). The direct drills placed the seeds and fertilizer in the same row. The whole annual fertilizer application (Table 1) was made during sowing. Granular ammonium nitrate NPK fertilizer was used, except at site 4 where liquid fertilizer (UAN 32) was used in the NT plots and the fertilizing level was lower compared to CT according to farmers experience on the need of N fertilizer on this plot. At site 4, samples were taken from the fields of private farmers cultivating and fertilizing the field according to their own frameworks. With the exception of tillage and drilling, field operations were carried out following the common farming practice in Finland. The sites were harvested in August.

Soil samples for the determination of total C and N, soil bulk density and potential denitrification were taken from the 0–20 cm soil layer once in 2009. Samples for mineral N were taken in the spring and fall of 2008 and three times in 2009 from the 0–20 cm soil layer. Soil particle size, porosity, total C and N, ammonium and nitrate in soil as well as frost and the amount of earthworm burrows were determined as in Regina and Alakukku (2010). Soil porosity was measured from three undisturbed soil core samples per plot. Pores of more than 30 μm in diameter were classified as macropores and pores with a diameter of 0.2 μm or less were considered micropores. Samples for total C and N were air dried and analyzed with a CN analyzer (CN-2000, Leco Corp, St Joseph, MI, USA). Mineral nitrogen (NO_3^- and NH_4^+) was analyzed by mixing a subsample of 100 g with 250 ml of 2 M KCl, then shaken for 2 h on an orbital shaker after which the extracts were filtered and finally analyzed after storage of 24 h in 4 °C. Depth of frost was measured with PVC tubes inserted in the soil in vertical pipes from all study sites. These tubes were filled with dilute methylene blue solution that turns colorless in temperatures below 0 °C thus indicating the location of the frozen soil layer (Richard and Brown, 1972). Estimation of the changes in soil C stocks was based on the equivalent soil mass method according to Ellert and Bettany (1995) and Lee et al. (2009). Soil temperature was measured using loggers (ElcoLog, Elcoplast Oy, Finland, measurement frequency 4 times/day) at a depth of 5 cm. The loggers were read twice a year, after tillage in the fall and before sowing in the spring. Soil moisture content was determined at a depth of 15 cm with a TRASE-TDR (Soil Moisture Equipment Corp., CA, USA), except for site 3 where soil moisture content was not measured. The proportion of water filled pore space (WFPS) was calculated by dividing the volumetric soil water content by total porosity. Potential denitrification in the soil was determined as described in Kanerva et al. (2005). Three 10 g subsamples were taken from each soil sample and amended with 1 mL of KNO_3 solution and 1 mL of glucose solution. The flasks were evacuated and flushed three times with helium. Acetylene (10%) was used to block N_2O reduction. The flasks were incubated at 25 °C and gas samples were taken at 30, 60 and 90 min and analyzed using a HP 6890 Series gas chromatograph (Agilent Technologies, Santa Clara, CA, USA).